# Uranium In-Situ Leach (Recovery) Development and Associated Environmental Issues [+]

by

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## Abstract

*Tertiary uranium roll-front deposits of South Texas exhibit an exceptionally strong bias toward long, narrow ore bodies. Understanding these deposits is paramount in accurately determining the uranium resource available and in designing in situ leach (ISL) patterns to minimize the volume of barren sand to be included in the leach field.*

*As in other mining projects, ore reserves are assessed by qualified professionals on the basis of the quantity and quality of the information available about the mineralization. To assess reserves in uranium roll-front deposits where ISL is under consideration, the number and distribution of the boreholes and core samples (to evaluate the local radiometric equilibrium and the amount and type of carbon present) and the quality of the geophysical logs (elevation control, radiometric calibration, panel settings, etc.) provide the required data to produce a meaningful assessment of reserves in preparation for ISL development.*

*In ISL projects, the design of the well field depends on the appropriate interpretation of where in 3-dimensional space the uranium mineralization occurs. This requires not only an understanding of the geologic conditions present but also of the hydrogeologic conditions such porosity and hydraulic conductivity of the various segments of the ore zone and associated barren zones to understand the ground-water flow regime.*

*Uranium exploration and mining are regulated by the State of Texas. Baseline studies consisting of comprehensive characterization of geography, geology, hydrogeology, and other topics are required by the State before mining can begin. To help the permitting process proceed smoothly, a strong community relations program should be made an integral part of management's function.*

## Introduction

With nuclear power re-emerging, exploration and development of uranium resources have accelerated over the past few years (Campbell *et al*., 2005; Campbell *et al*., 2007). Numerous investigations were conducted by the western states and by the federal government supporting uranium exploration beginning in the late 1940s and increasing in the 1960s through the 1970s. The Natural Uranium Resource Evaluation Program (the now well-known NURE Program) produced hundreds of reports to further the exploration for uranium resources in Texas as well as in other states with potential for uranium occurrences. For the southwest U. S., Campbell and Biddle (1977) provided a review for areas outside known areas with potential for uranium mineralization. Criteria for locating uranium in Texas were developed in a number of reports, notably by Flawn (1967), Norton (1970), Fisher, *et al.* (1970), Grutt (1972), Eargle, *et al.* (1975),

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Galloway, *et al*. (1979), Henry, *et al.* (1982), and Smith, *et al.* (1982), among others. A comprehensive uranium bibliography is also available that includes references to the NURE microfilm library, see: http://www.mdcampbell.com/uraniumreferenceslibrary.pdf

## GEOLOGY OF URANIUM OCCURRENCES

To efficiently develop uranium resources by the environmentally friendly in situ method, the local geology and the various configurations of the mineralization must be well understood. In general, where an oxidized uranium-bearing ground water encounters a reducing environment, uranium mineralization in unoxidized form precipitates in preferred areas along the margins of major fluvial systems in the form of the classical roll-front (Figure 1).

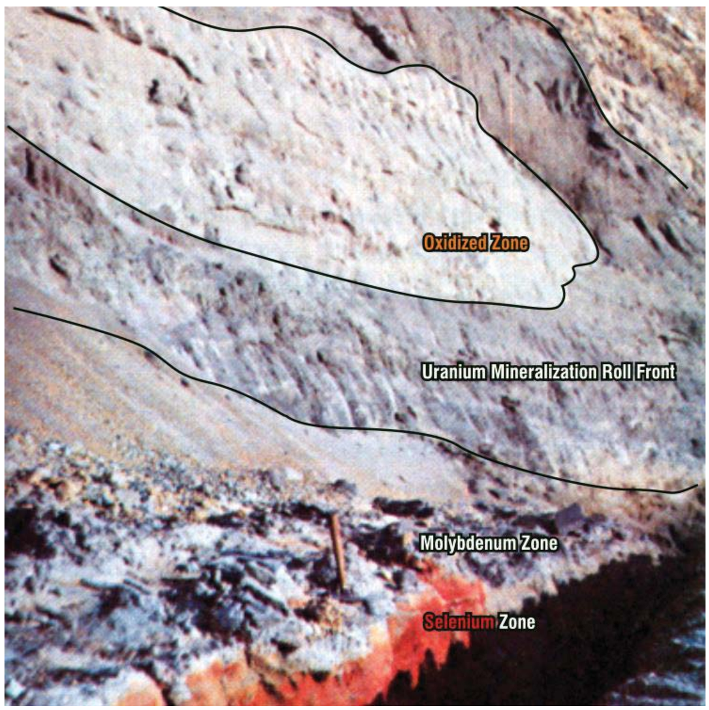


**Figure 1 - Typical Uranium Roll Front in Wall of Open-Cut Mine in South Texas from the 1970s (After Dickinson and Duval, 1977).**

Uranium also forms in association with faults, which can serve as sites of ground-water flow retardation and areas where a reducing environment created by methane or even hydrogen sulfide from below precipitates uranium in a complex geobiochemical cell. Rackley (1968, 1971, 1975, and 1976) summarizes the geological and biogeochemical factors involved in similar Wyoming uranium occurrences (Figure 2).

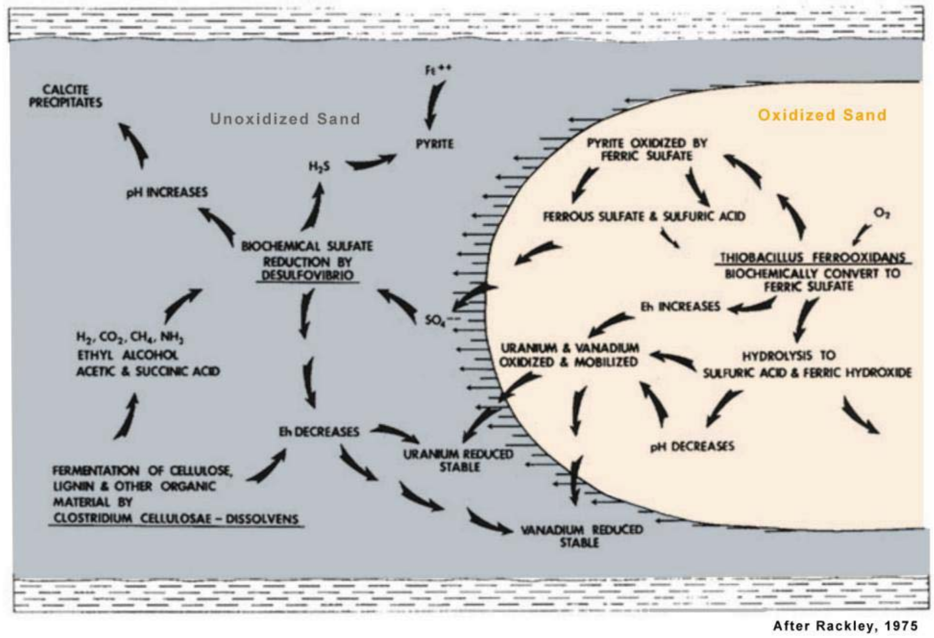


**Figure 2 – Environment of Wyoming Tertiary Uranium Deposits (After Rackley, 1975)**

Rubin (1970) illustrates the typical relationships between geophysical logs and the geology and mineralogy of uranium mineralization in Tertiary sands (Figure 3). Both of these papers are as applicable today as they were in the 1970s.

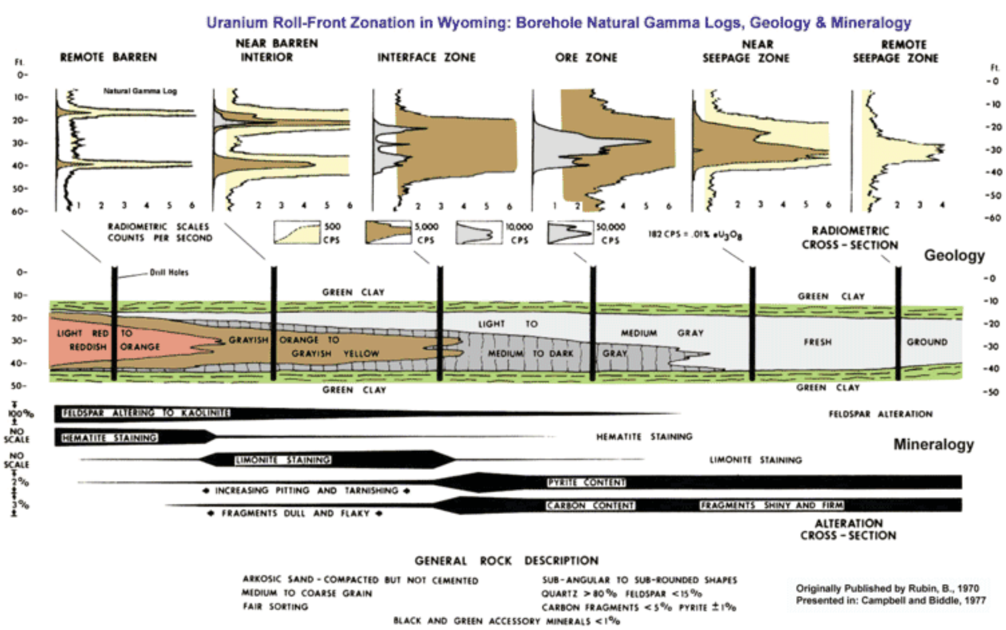


**Figure 3 – Uranium Roll-Front Zonation in Wyoming: Borehole Natural Gamma Logs, Geology & Mineralogy (After Campbell and Biddle, 1977; After Rubin, 1970)**

Although emphasizing the classical roll-front allows for a straightforward description of the mechanisms involved in the subsurface, favorable areas often are more complex. For example, many of the ore deposits in Texas have occurred in the classical roll-front configuration, but many others occur in association with faults, either along simple linear trends or within grabens or complex fault structures, especially those with upthrown blocks toward the coast. These faults may have been active syngenetically with deposition or well before or after the onset of mineralization. Eargle, *et al.* (1975) and Fisher, *et al*. (1970) suggest that methane or hydrogen sulfide emanating from sources at depth, or from anaerobic bacteria acting with these organic materials in creating metabolic by-products, provide a reducing environment that promotes uranium precipitation. In Figures 4a and 4b, the association of the mineralization with the fault is apparent.

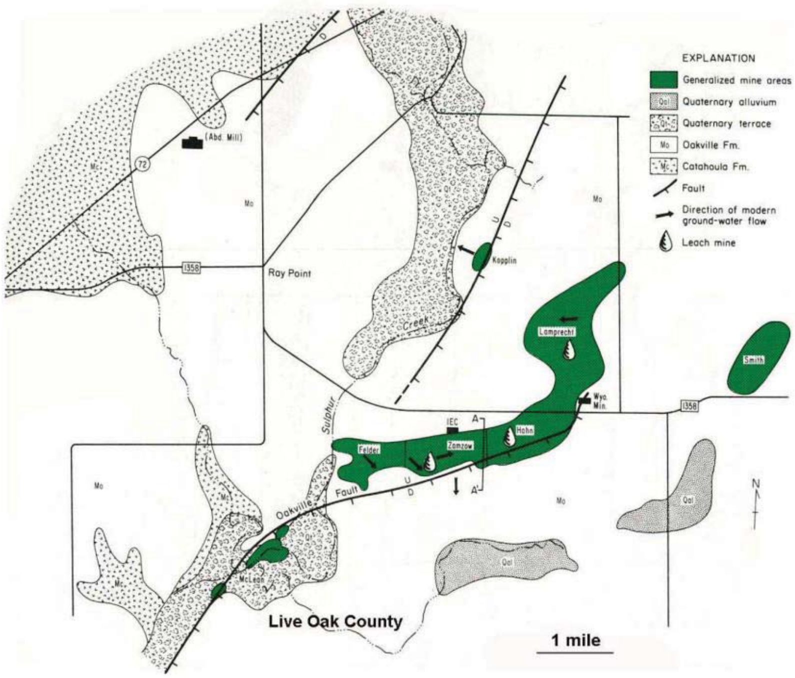


**Figure 4a – Map View of Fault-Related Uranium Mineralization in Live Oak County (After Galloway, W. E., R. J. Finley, and C. D. Henry, 1979)**

Other requirements are present in some mineralization as well. The presence of lignite or interstitial carbonaceous matter, either as stringers within sand intervals or in the silt or clay intervals above or below the sand, are not widespread in the known uranium occurrences in Texas but may play an important part in uranium mineralization in other intervals of Tertiary sediments where a source of uranium is available from nearby sediments or rocks. These prospects would be considered frontier areas for exploration in Texas.

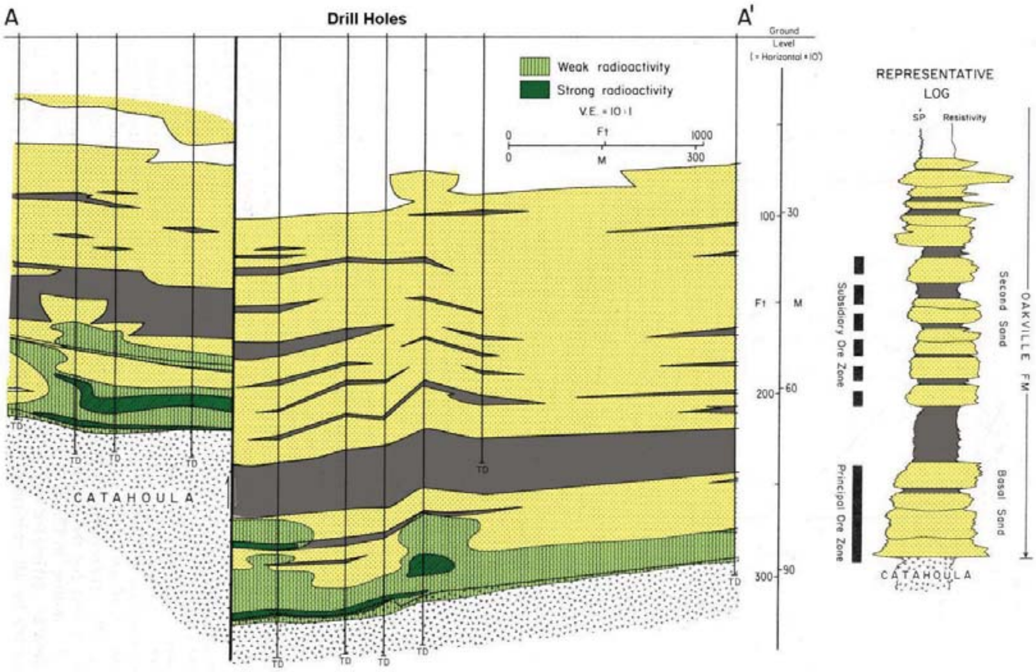


**Figure 4b – Cross Section of Fault-Related Uranium Mineralization in Live Oak County (After Galloway, W. E., R. J. Finley, and C. D. Henry, 1979)**

The uranium boom in Texas of the 1970s to1980s involved uranium mineralization at the surface and in shallow deposits, some of which were developed as open-pit mines. In time, exploration developed down dip and now focuses on deep targets developed by in situ recovery methods. Figure 4c shows the previous prospect areas and the areas of present interest.

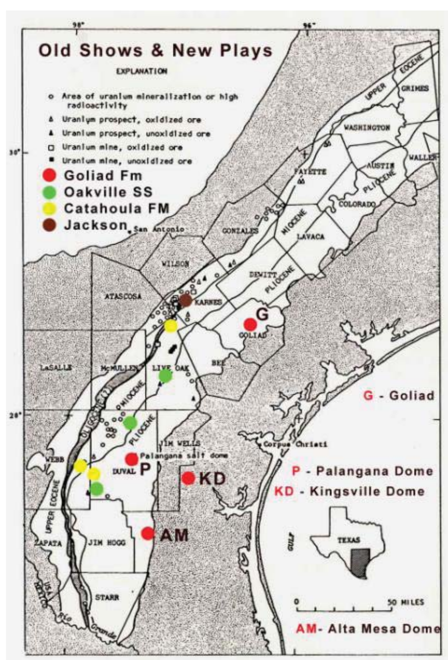


**Figure 4c – Old Shows of Radioactivity & Areas of Recent Activity (After Eargle and Weeks, 1975)**

The use of hydrochemistry of the ground water helps to characterize the subsurface environment for uranium exploration. Defining the hydrochemical facies also places any site into its specific environmental context for permitting purposes (Figure 5).

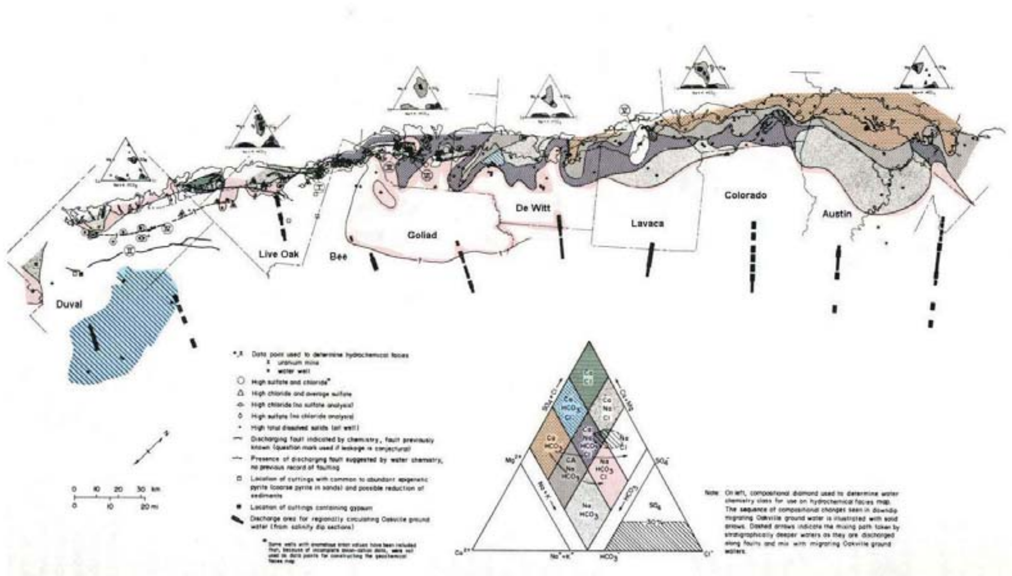


**Figure 5 – Hydrochemical Facies Map within the Oakville Aquifer**
**(After Smith, G. E., W. E. Galloway, and C. D. Henry, 1982)**

## DRILLING TO ESTABLISH URANIUM RESERVES

To identify the oxidation-reduction front in a prospective sand, exploration drilling requires a series of drill sites using typical water-well rigs. Although ore deposits as deep as 2,000 ft are now considered to be potentially economic because of the higher market price for yellowcake, each hole is a financial commitment by the exploration company that requires careful selection. For example, the results from Hole 3 shown in Figure 6 have indicated the presence of oxidized sand. The next site is Hole 4, which encounters a reduced sand suggesting that the next drill site (Hole 5) should be half the distance between Holes 4 and 3. If Hole 5 is still in reduced sand, the next drill site (Hole 6) should be located half the distance between Hole 5 and Hole 3.

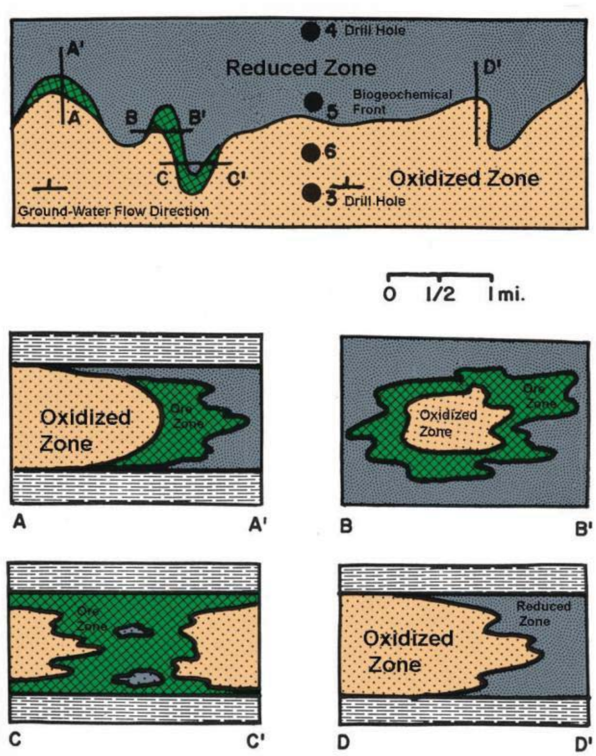


**Figure 6 – Drilling for Mineralization (After Campbell and Biddle, 1977)**

If the line of drill holes had been placed one mile to the west (to the left in Figure 6), Holes 5, 6, and 3 would have encountered uranium mineralization. Keeping track of the differences between oxidized and reduced sediments is not difficult, but when sediments have been re-reduced by secondary introduction of reducing agents such as methane, identification can be challenging.


**Figure 6a – Typical Oxidized and Reduced Sediments from a Texas Operation.**

The cross-sections shown in Figure 6 illustrate the typical configuration of the mineralization that would be anticipated. A close-up view of the color difference between oxidized and reduced sediments from a producing Texas recovery operation is shown in Figure 6a. This knowledge then is used to install the injection and production wells in preparation for in situ recovery of the uranium mineralization.

Combining knowledge of the local geological conditions with the results from drilling, including borehole geophysical logs and core descriptions, the location of the mineralization will be known with some certainty. In order to accomplish this level of understanding, spacing of drill holes down to 25 ft of separation may be required.

Geologists are responsible for executing exploration programs. In the 1970s and 1980s, approximately 2,000 professional geoscientists were working on uranium projects in the U. S. Presently, only some 400 geologists and only a few qualified hydrogeologists are working in the field. State geoscience licensing in Texas, Wyoming, Washington, and elsewhere has reinforced the upward trend in professional competency and responsibility to the general public in the analysis of uranium reserves and environmental compliance for private mining companies as well as for those on the stock markets. The responsibility to conduct reserve analyses for publicly traded mining companies resides with the geologists. To staff up, it will take some time to train new geologists and hydrogeologists. This lack of trained personnel may inhibit yellowcake-production schedules, and a lack of available drilling rigs and geophysical well-logging services, may slow the progress of exploration and evaluation of prospects and of development in general.

Geologists calculate uranium reserves by using downhole, natural-gamma logging equipment that has been appropriately calibrated and by obtaining cores of the ore to evaluate the radiometric equilibrium of the uranium in the ore by laboratory analysis. Many mineralized zones in Texas are characterized by very young uranium ore, those whose radiogenic daughter products have not yet reached equilibrium with the chemical content of the ore. This can present problems in assessing the grade (and therefore the reserves) because the natural gamma log would be under-reporting the actual grade of the ore.

Figure 7 illustrates a typical drill log and calculation sheet for estimating reserves. To address the relationships between indicated radioactive ore (termed ${}_{e}U_3O_8$) and the actual chemical content of that ore (termed ${}_{c}U_3O_8$), new logging equipment is now available to offset this problem. As indicated above, the age of the mineralization in Texas is so young in places that insufficient time has passed for the uranium to degrade into its daughter products $Bi^{214}$, $Tl^{208}$, and other products that are radioactive and are reported by the natural gamma log normally used for uranium exploration. In the past, core samples of ore had to be sent off to laboratories requiring weeks for turnaround before the equilibrium of the ore could be assessed and applied to in-place uranium reserve assessments.

Because ISL development depends on an appropriate reserve assessment and on carrying out development and meeting regulatory requirements in protecting human health and the environment, the processes involved should be guided by qualified, licensed professional geoscientists and geotechnical engineers.

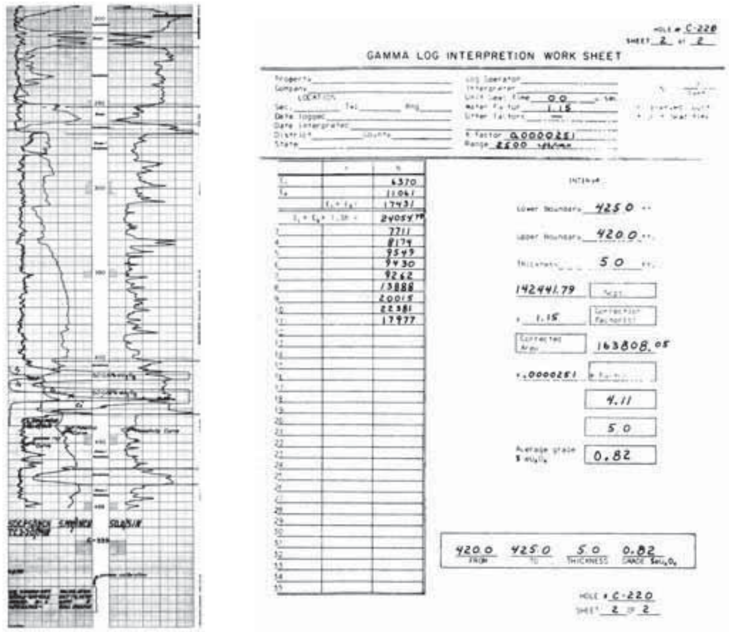


**Figure 7 – Geophysical Well Logs, Including Natural Gamma, Resistivity and SP Logs with Reserve Grade Calculation Sheet (After Century Geophysical Corporation Brochure, 2007)**

## IN SITU LEACH (RECOVERY) DEVELOPMENT

The technical literature on in situ mining is growing as experience widens within industry (Anthony, 2006; Knape, 2006, Mudd, 1998 (a typical adversarial perspective), and other sources presented in our Introduction). The wells installed to characterize and recover the dissolved mineralization should be designed at the outset of production to serve also as monitoring wells that may be used later for monitoring and other regulatory purposes. This is required because the ISL method represents an example of the balance between the development of a vital natural resource and the protection of the aquifer. A typical ISL system is illustrated in Figure 8.

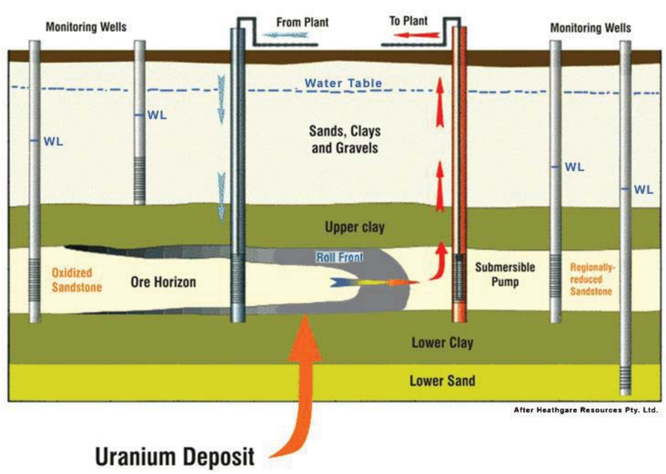


**Figure 8 – Typical In Situ Recovery System with Monitoring Wells (After South Dakota Department of Environment and Natural Resources, 2006)**

In the production of uranium, mining no longer requires open-cut surface mines as in the past. New environmentally friendly methods have developed substantially since the late 1970s. Mining uranium in Tertiary sandstone deposits in South Texas, Wyoming, Kazakhstan, and elsewhere now incorporates ISL methods that involve water-well drilling technology and common industrial ion-exchange technology similar to household water-softening methods.

Because the uranium ore has formed naturally in aquifers often used for drinking-water supplies elsewhere along the trend, the part of the aquifer being mined by ISL methods is prohibited by the State to be used as a source of drinking water. In addition, the area of influence of nearby large-capacity water wells needs to be carefully monitored to avoid drawing the naturally contaminated ground water away from the uranium production area. The State of Texas requires that all water wells located within 0.25 mi of the production area be monitored by the mining company semi-annually. However, some companies are voluntarily enlarging this radius in an effort to be a "good neighbor".

The leaching agents used in ISL are typically $O_2$, $CO_2$ and, in some cases, other fluids, all of which are non-toxic and are easily recovered by pumping. The pumping cycle entails injection of barren fluids, $O_2$, $CO_2$, etc., followed by the recovery of uranium-bearing fluids for making yellowcake from ion exchange resins in the plant on the surface. A typical 5-spot pattern is used in various configurations to dissolve the ore and pass it on in a solution of low uranium concentration to the plant for processing (Figure 9).

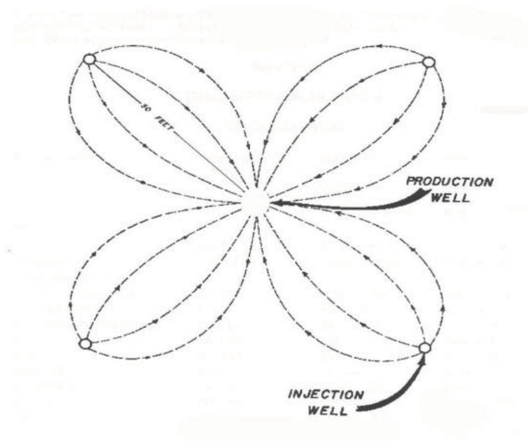


**Figure 9 – Typical 5-Spot Injection / Production Well Pattern**

The surface footprint of in-situ recovery operations is minimal and easily removed after completion, allowing previous land use such as grazing and farming to resume. Well spacing of the injector and recovery wells are shown in Figure 10 of a present Texas operation. As seen in the background of the photo, such operations can also be conducted in and around normal rural activities, just as in oil & gas operations.

**Figure 10 - Well Spacing of Injection and Recovery Operations at a Present Texas Operation.**

## ENVIRONMENTAL ISSUES

To a large extent, in situ mining of uranium is both a natural resource development project and a natural, contaminant-remediation project. Although uranium ore is a natural energy resource, it is also a bacterial waste product that was formed within the bio-geochemical cell of the roll-front. In other terms, uranium ore is a by-product of anaerobic bacterial respiration that forms within the bio-geochemical cell (see Figures 2 and 3). Both rely heavily on, and are driven by, geological and hydrogeological processes including: the hydraulic conductivity of the sands involved either within the ore zone or in the monitored sands above and below the ore zone; the hydraulic gradient of each of the sands; the porosity of the sands involved and of the ore-zone porosity. To this must be added the hydrochemistry of ore zone fluids and injection fluids (both within the ore zone and at proximal and distal parts of the aquifer designated by the state as a uranium production zone).

It is the responsibility of the mining company (and required by state regulatory agencies) to install strategically located ground-water monitoring wells to be sampled periodically for fluids that may have escaped the production cycle. These monitoring wells must monitor not only the perimeter of the production area, but also both the overlying and underlying aquifers.

The mine's hydrogeological staff is responsible for monitoring the behavior of the fluids and associated hydrochemistry during the in situ leaching of the uranium ore zones and for monitoring the data generated from sampling the surrounding monitoring wells (Figure 11).

**Figure 11 – Typical Monitoring Well Nest for Monitoring above and below the Production Zone**

Protecting upper and lower aquifers from incursions of the production fluids requires understanding the hydrogeological conditions in and around the production site. Regulatory personnel work with the mine's staff to ensure that the mine meets the regulations written to protect the aquifers that are located outside the designated production areas.

## ENVIRONMENTAL REQUIREMENTS AND COMPANY POLICIES

Uranium exploration area permits in Texas are granted by the Texas Railroad Commission of Texas. ISL mining in Texas is regulated by the Texas Department of State Health Services (DSHS) for the processing plant (and the radioactive materials license) and the Texas Commission on Environmental Quality (TCEQ) for the underground injection control (UIC) aquifer exemption, the Class III UIC permit and production area authorizations (PAA) for mining, and the Class I UIC nonhazardous well permit for wastewater disposal. The TCEQ also oversees cleanups of releases and spills of the leaching solution from the well field and associated pipelines. TCEQ applications for conducting in situ mining of uranium and production area authorization are available online at the TCEQ website:

http://www.rrc.state.tx.us/rules/documents/prop-repeal-and-new-Ch11-uranium-rules.pdf

Drinking water aquifer exemptions are granted by the U. S. EPA and mine safety is overseen by Mine Safety Health Administration (MSHA), mining's equivalent of the Occupational Safety Health Administration (OSHA). Other agencies that may need to be consulted are the Texas Parks and Wildlife, the Texas Historical Office, and the U.S. Army Corp of Engineers.

In order to conduct ISL mining, a complete environmental assessment of the site needs to be conducted. This assessment includes both surface and ground-water characterization to be used to establish monitoring baselines and ground-water restoration concentration levels (See Figure 12). The environmental assessment has become more important as the general public has become more environmentally aware. ISL mining also is under increased public pressure to prove that it is a safe operation and that any required remediation of the aquifer can be accomplished in a reasonable period of time.

A properly conducted assessment can be used to show that, despite the general public's impression, the aquifer that contains the uranium mineralization contains both suitable and unsuitable drinking water quality.

**Figure 12 – Coring Operations to Evaluate Uranium Mineralization and to Characterize Aquifers Above and Below Mineralized Zones**

While the aquifer may contain suitable drinking water quality, the area of the aquifer containing uranium mineralization is naturally contaminated and has been contaminated long before humans could drill water wells. The fact that the aquifer contains uranium mineralization and associated contaminated ground water has been misunderstood by landowners, which has resulted in numerous protests and added costs that the mining company must spend to respond to this misunderstood subject.

Baseline environmental condition evaluations are essential to provide reasonable mine closure guidelines and are conducted over the course of a year so as to determine seasonal variations. They fall under the general categories of physical, biological, and socio-economic investigations.

Physical characteristics to be included in environmental assessments are: topography, geology, hydrology/hydrogeology, climate, soils, air quality, and radiologic background. Topography is important, not only because of the factors involved in moving water up or down hill, but to predict potential spill-flow directions for cleanup purposes. In addition, a variety of protective measures for injection, production, and monitoring wells and associated equipment may be required if the uranium deposit is located above a flood plain. Surface geologic information is important for determining surface faulting that could affect pipelines and impact processing plants.

Hydrology/hydrogeology will be used to provide a baseline for monitoring and remediation purposes, determining the ore controls, and placement of disposal wells, if needed. Climate data will provide information on wind speed and direction to facilitate air modeling in case of vapor/dust releases, and temperature and rainfall information can contribute to the design of holding ponds. Soil information is used to determine infiltration rates in case of spills or releases from pipelines, holding ponds, etc.

Collection and analysis of air-quality information will be used to provide a baseline for monitoring purposes. Radiologic background also will be used to provide decommissioning guidelines to be applied when the production equipment is removed from the site.

Collection and analysis of biological factors include flora and fauna (both terrestrial and aquatic), endangered species, and radiologic analyses of selected samples. These factors allow the mining company to make preparations for dealing with environmentally sensitive locations. These preparations may include taking added precautions to protect these areas, altering the size or shape of the mining grid, or avoiding an area completely.

Socio-economic issues have become increasingly important over the recent decades. Impacts on local populations may disrupt local lifestyles, but there also may be positive impacts by providing employment in an otherwise depressed area. An assessment of current resource use, such as agriculture, wildlife harvesting, fishing, and tourism is important. Cultural issues must be considered, including both current conditions, and archaeology and history. The costs and benefits must be carefully weighed. Knowledge of these factors would help to reinforce community relations.

## ISSUES TO BE ADDRESSED

Some of the more important issues that should be considered / accepted are:

- **What type of mining solution should be used?** There are pros and cons to each of the types available.

- **What is a reasonable cleanup goal?** Remediating a site to drinking water levels is no longer required by the state because this action was deemed unreasonable since the site was naturally contaminated already. The general public will need to understand why and how the cleanup goals have been set. In more than one case companies have been criticized about the cleanup levels set, even though these levels were well below the human health risk levels approved by the state regulatory agency. Good community relations through communication are an important function of the mining company's management.

- **Are there any abandoned wells that need attention?** Identification of old boreholes may be required to make sure they are properly sealed before ISL mining begins. Because many of the new deposits were discovered in the 1980s, it is entirely possible that, by today's standards, they were improperly sealed. It once was common practice to simply fill the hole with drilling mud and then insert a 10-foot concrete plug three feet below the surface. These plugs were known to slip, and old boreholes that were thought to be properly abandoned would cave-in and remain open to the surface for many years. These open borings serve as routes for the migration of mining fluids to both higher and lower aquifers. There have been cases reported of these old boreholes being discovered by the fluid geyser that resulted when the nearby injection wells were initially operated.

- **What is the best way to dispose of excess wastewaters?** By evaporative ponds or disposal well. Evaporative ponds are thought to be more environmentally friendly, but may be unfeasible in areas of high humidity or low temperatures. Ponds such as these often leak, creating cleanup problems later during closure, so ponds should be avoided if possible. In some mines, above ground storage tanks are used to temporarily contain wastewaters. Disposal wells may be uneconomical if they need to be drilled too deep to reach an appropriate injection zone similar to those zones used for brine disposal from local oil and gas wells. It has also been suggested that two disposal wells should be installed, in case a problem develops with one of them.

- **Are all company employees properly trained in the handling of the equipment and of radioactive materials?** They also need to be made aware of the danger of radiation exposure from yellowcake dust and why it must not be allowed to escape into the general environment. Appropriate plant designs and operation and maintenance practices can minimize such concerns.

- **Have all neighboring water wells been identified?** All water wells within 0.25 mi of the mining area need to be included in any monitoring program for periodic sampling and laboratory analysis. Some mining companies are extending this radius to insure that the coverage is suitable.

- **Is a well-established emergency-response procedure in place and are all employees skilled in its use?** This should be an established mining company management function.

With the general public becoming more environmentally conscious, it is imperative that an ISL mining company is prepared to respond to all spills and releases immediately and answer any and all questions from concerned persons openly and honestly. This may not insure that problems and misunderstandings will not occur, but a community approach should prevent most of the associated problems.

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